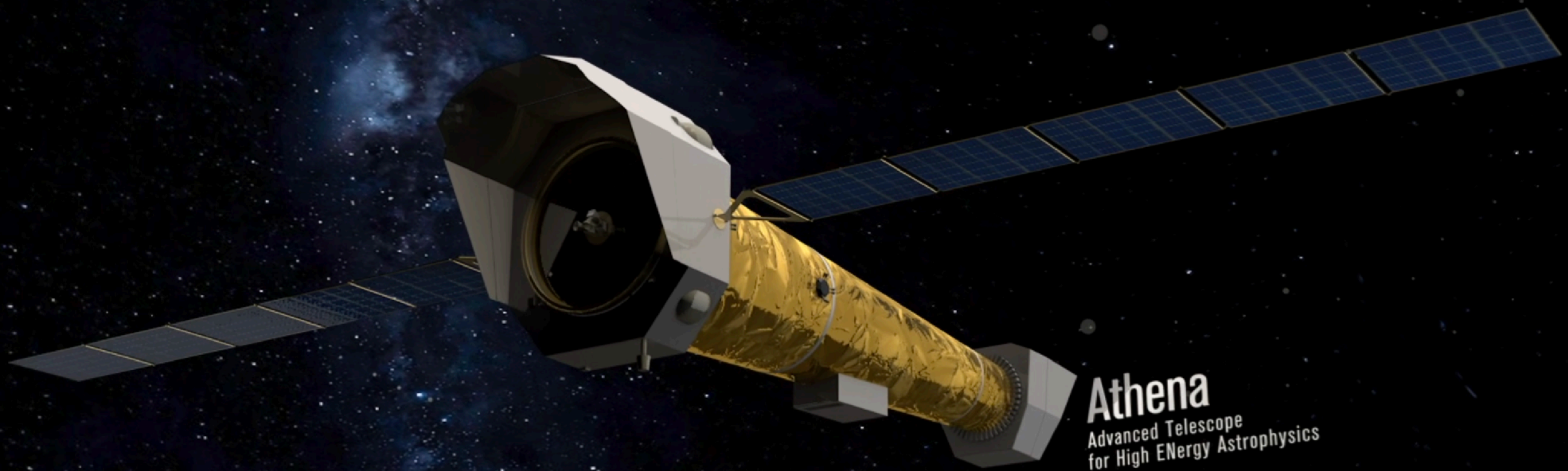


GROUPS AND CLUSTERS OF GALAXIES WITH ATHENA

Etienne Pointecouteau
(IRAP, Toulouse)



Atelier Amas France — 10/12/2020



ATHENA

2

Advanced Telescope for High ENergy Astrophysics

The next generation of X-ray observatory after the XMM-Newton and Chandra, after XRISM

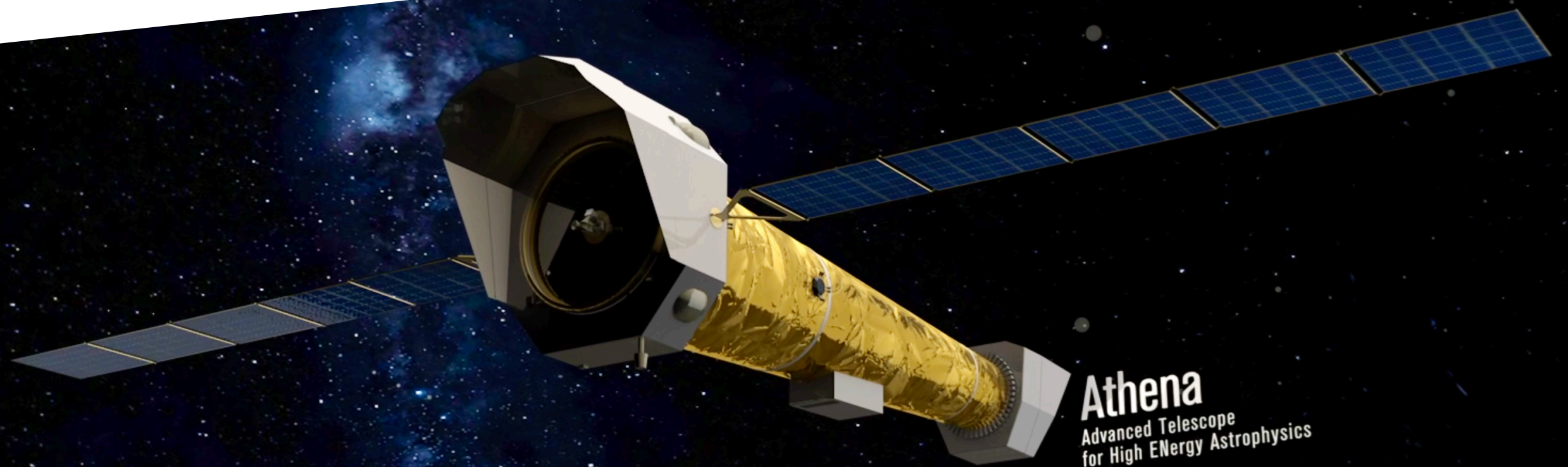
Second Large mission of the ESA's Cosmic Vision science program

Operating simultaneously with major space/ground-based facilities (ELT, SKA, LISA)

Implementing to the Hot and Energetic Universe

How does ordinary matter assemble into the large scale structures that we see today?

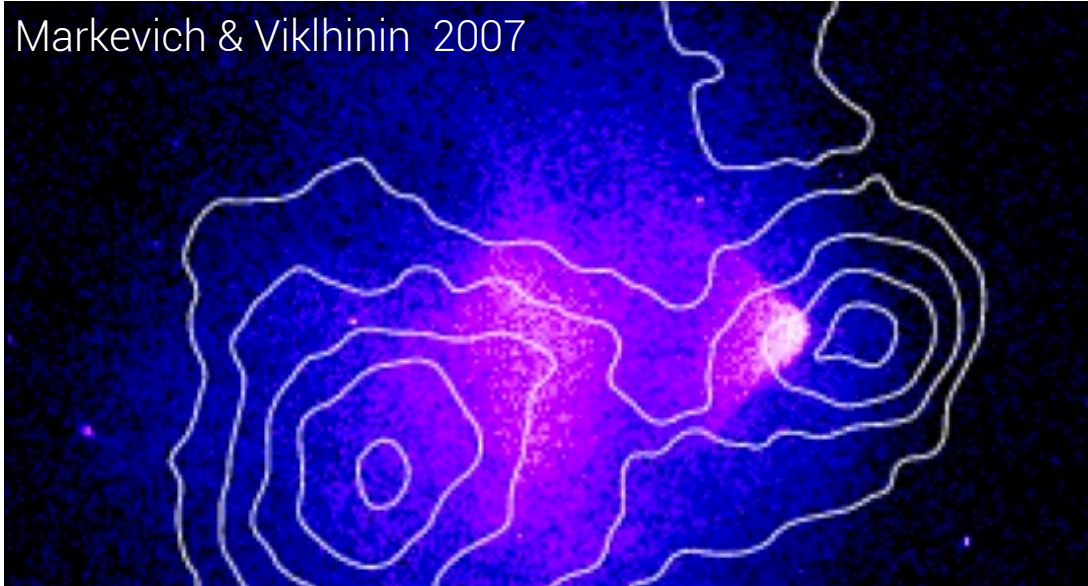
How do black holes grow and shape the Universe?



THE HOT UNIVERSE

3

Markevich & Vikhlinin 2007



Assembly of structure

Credits: NASA



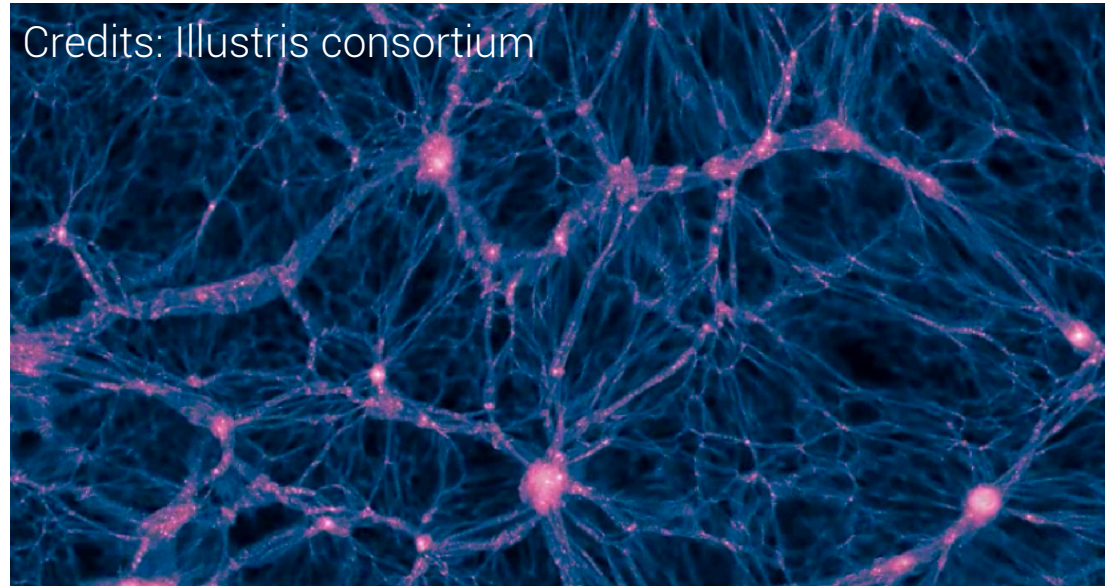
Chemical Enrichment

McNamara & Nulsen 2012



Feedback and co-evolution

Credits: Illustris consortium

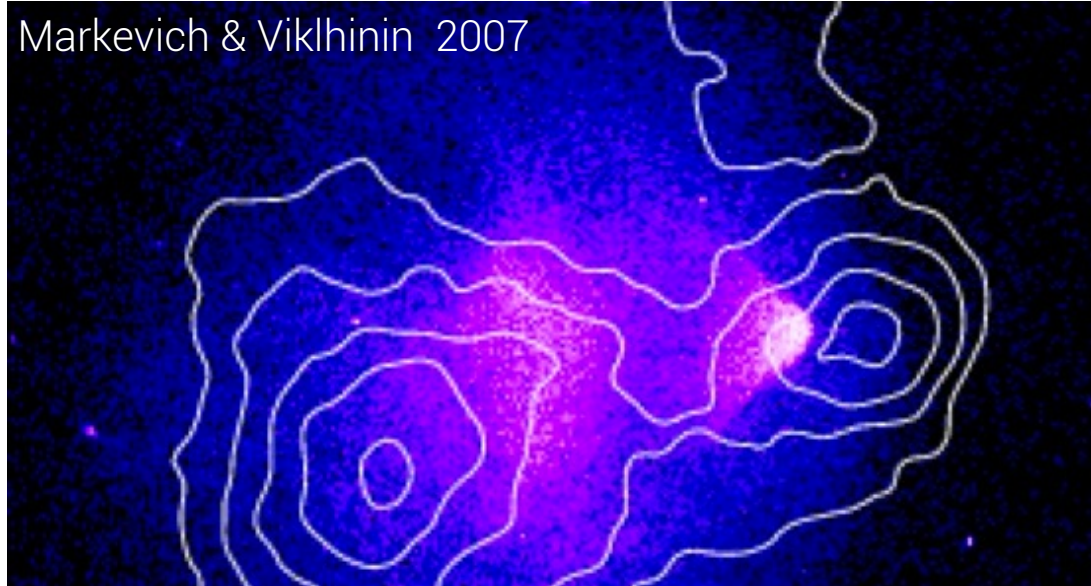


Baryons at large scale

THE HOT UNIVERSE

4

Markevich & Vikhlinin 2007



Assembly of structure

Credits: NASA



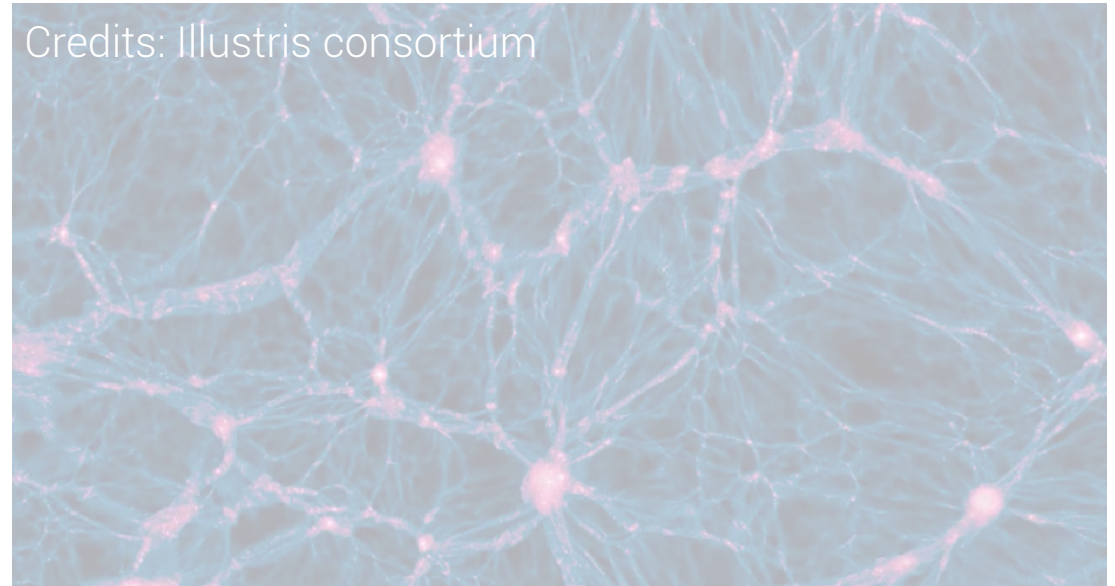
Chemical Enrichment

McNamara & Nulsen 2012



Feedback and co-evolution

Credits: Illustris consortium

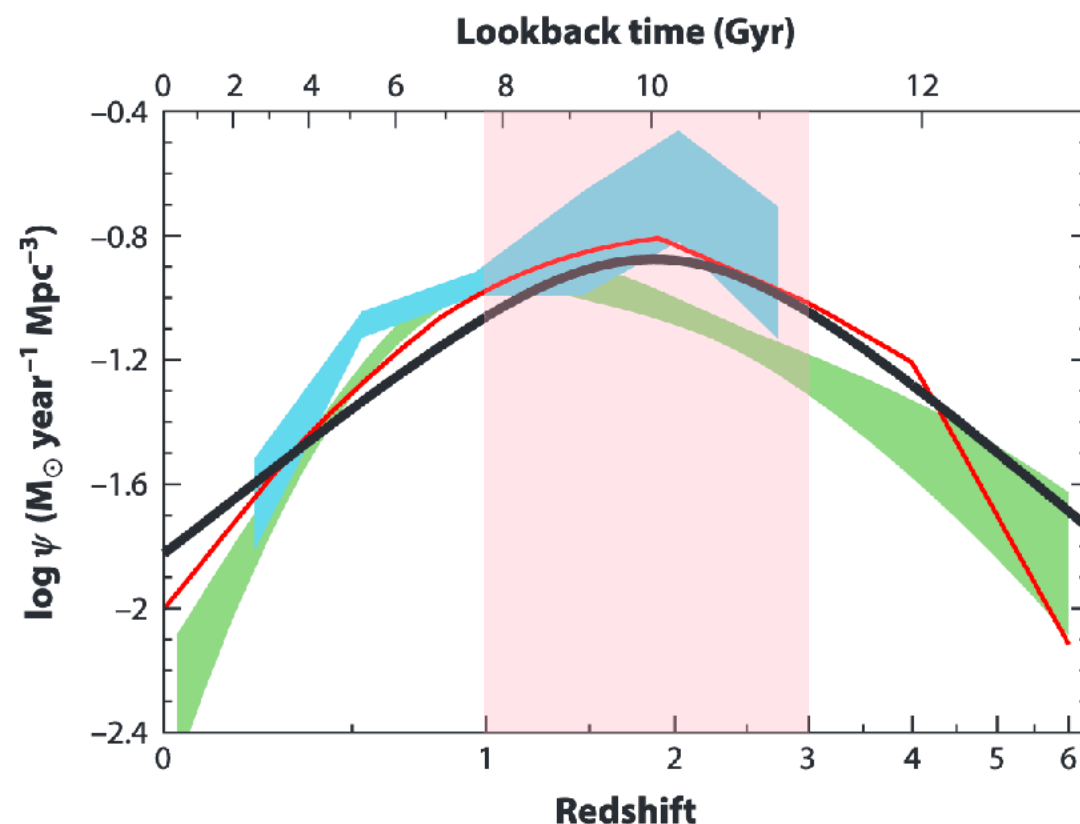


Baryons at large scale

FEEDBACK AND CO-EVOLUTION

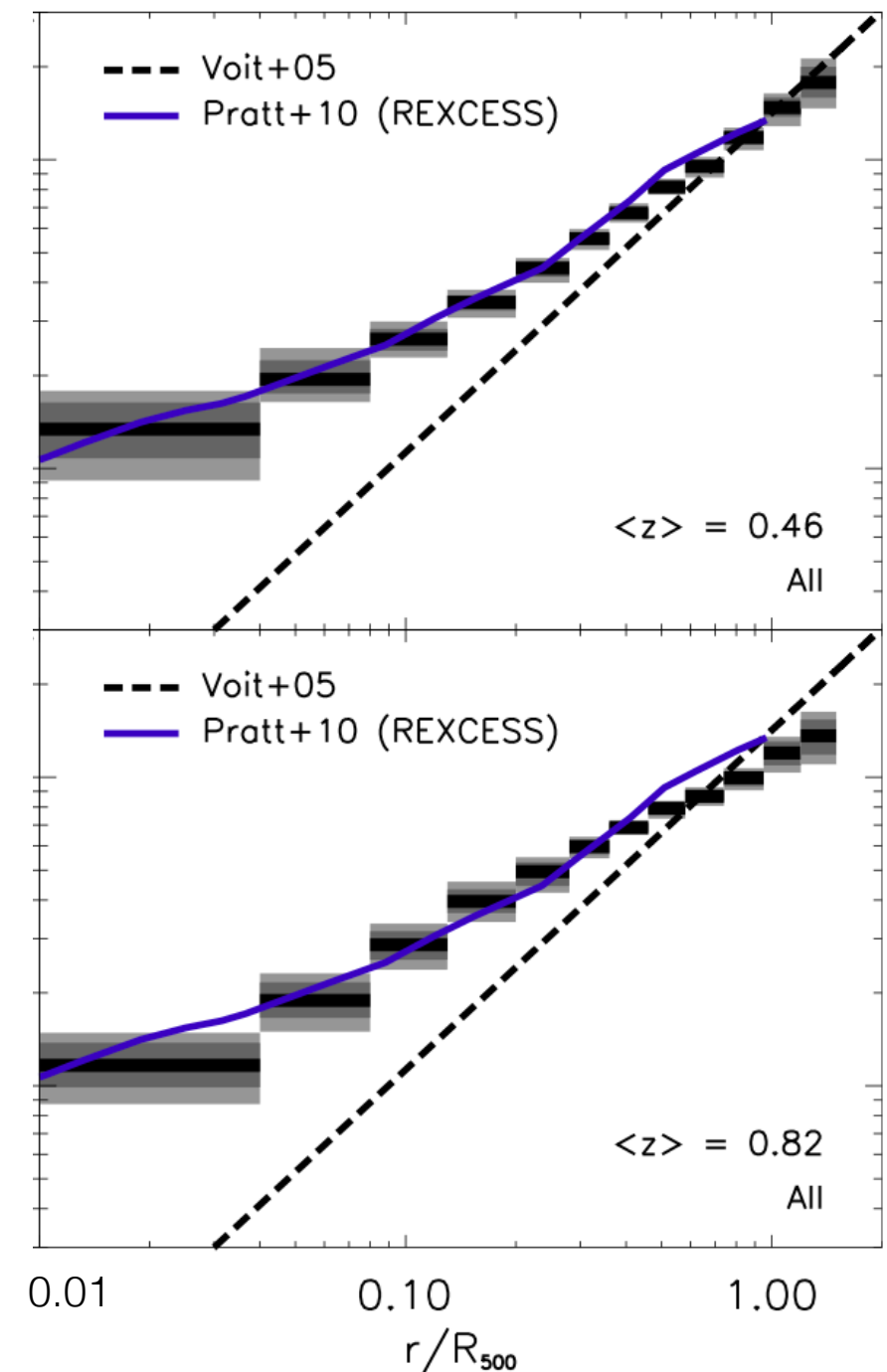
5

Groups and clusters form at the apex of astrophysical activities of the Universe



Star formation and SMBH accretion history
(Madau & Dickinson, 2014)

McDonald et al. 14



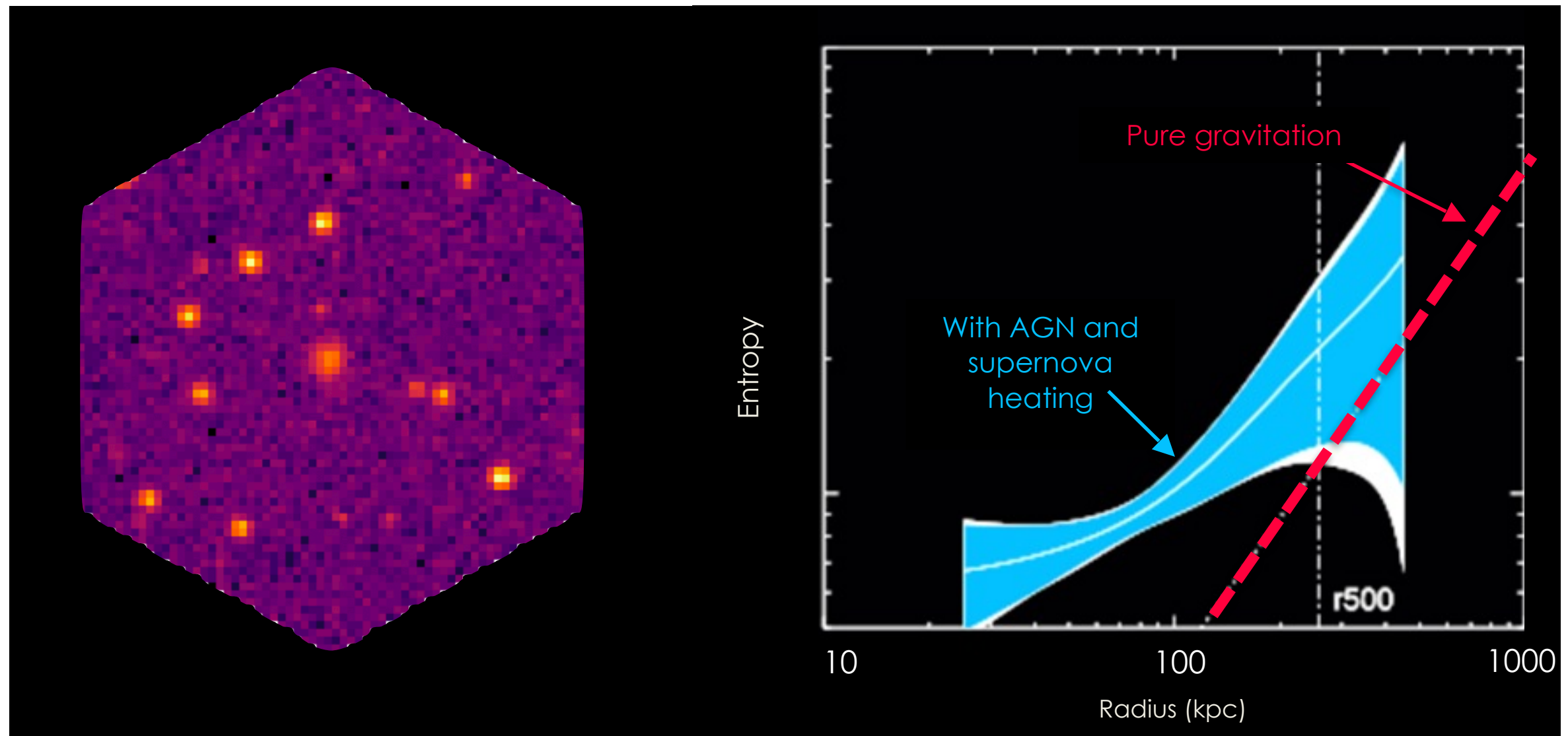
Entropy profiles out to $z \sim 1$
(McDonald et al. 2014)

FEEDBACK AND CO-EVOLUTION

6

Evolution of the gas thermodynamics during collapse and growth of halos

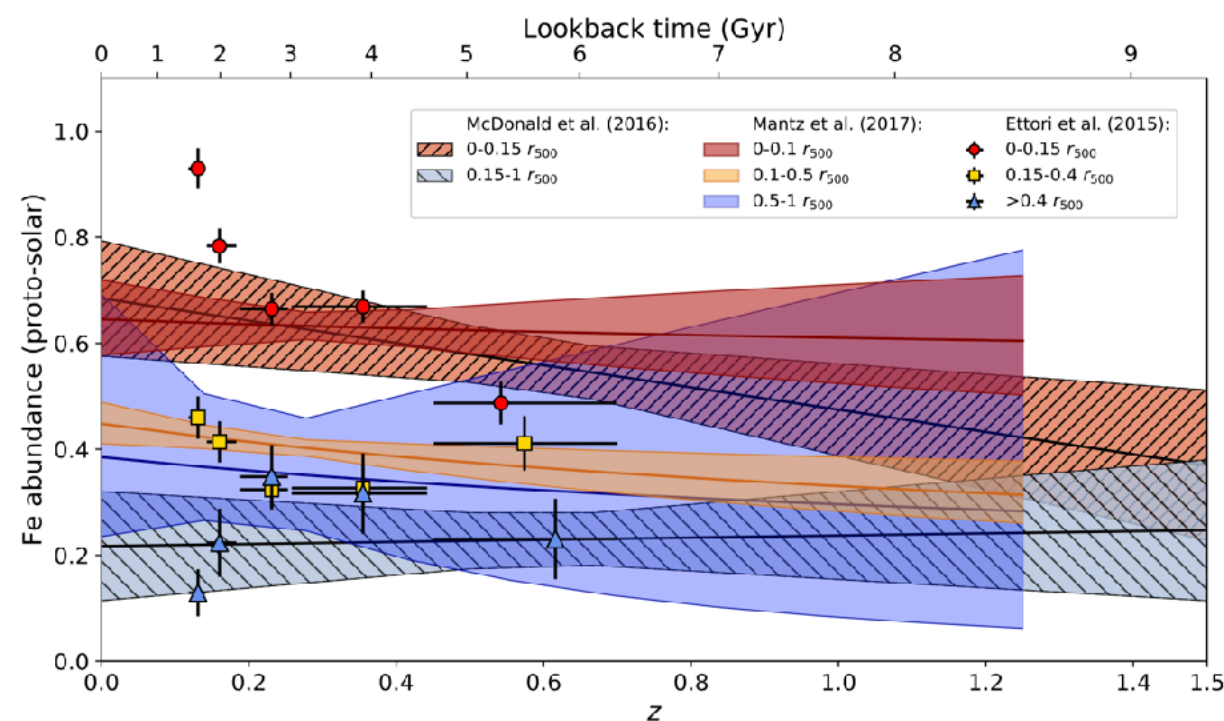
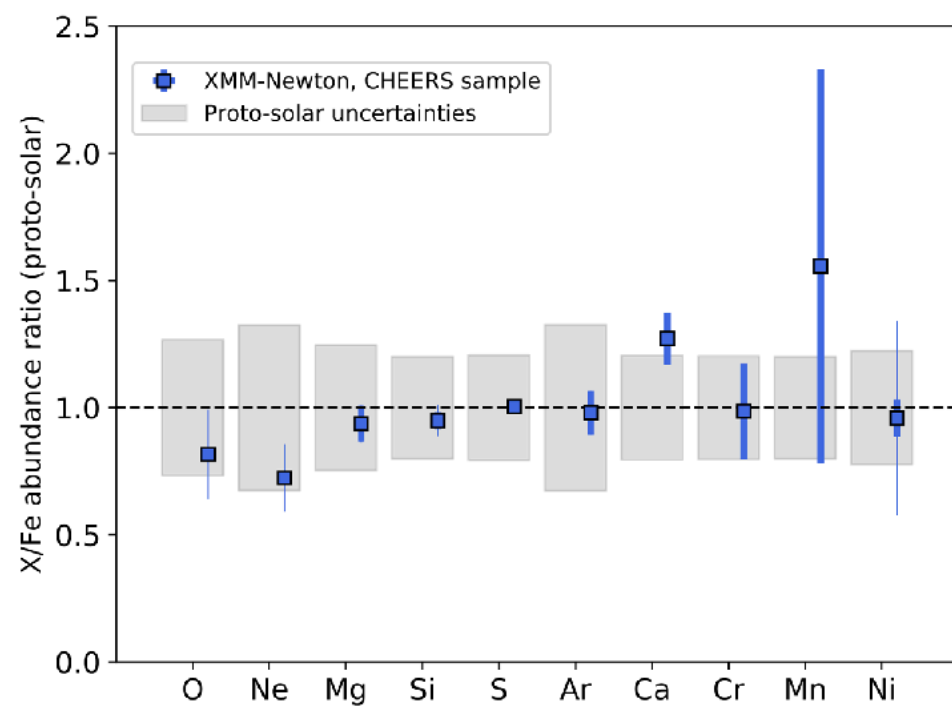
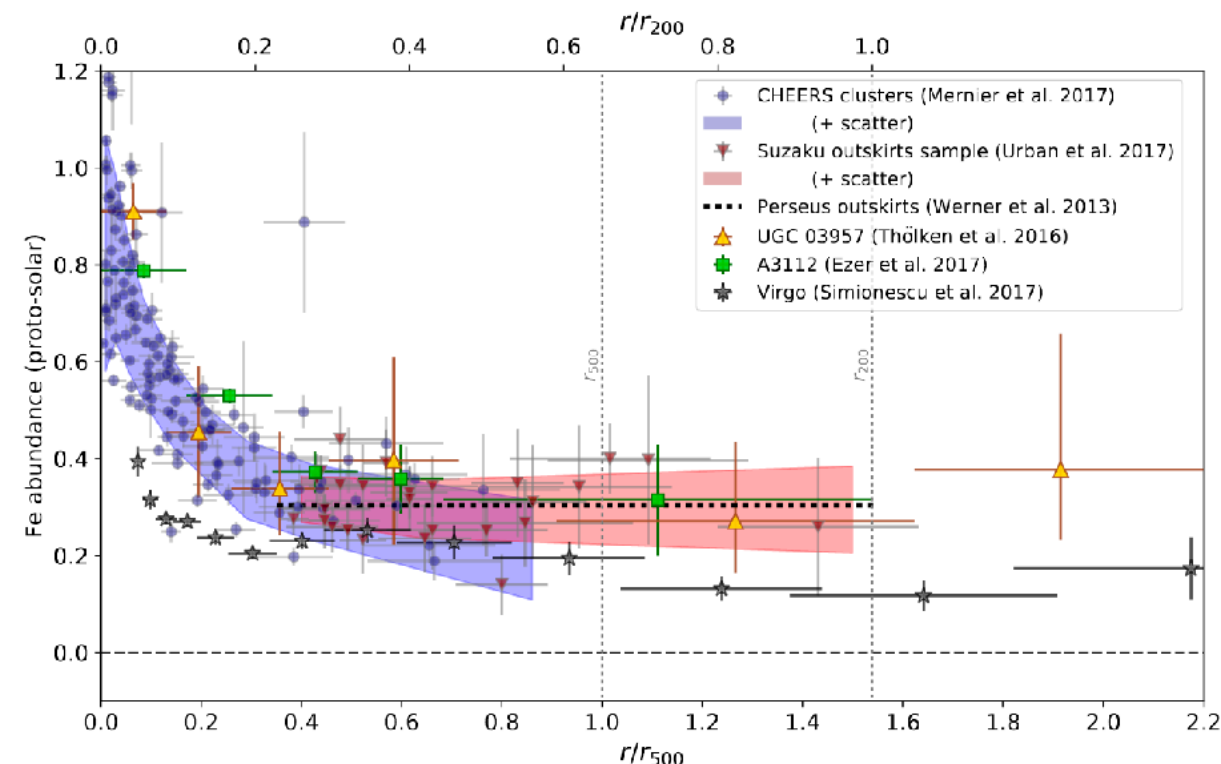
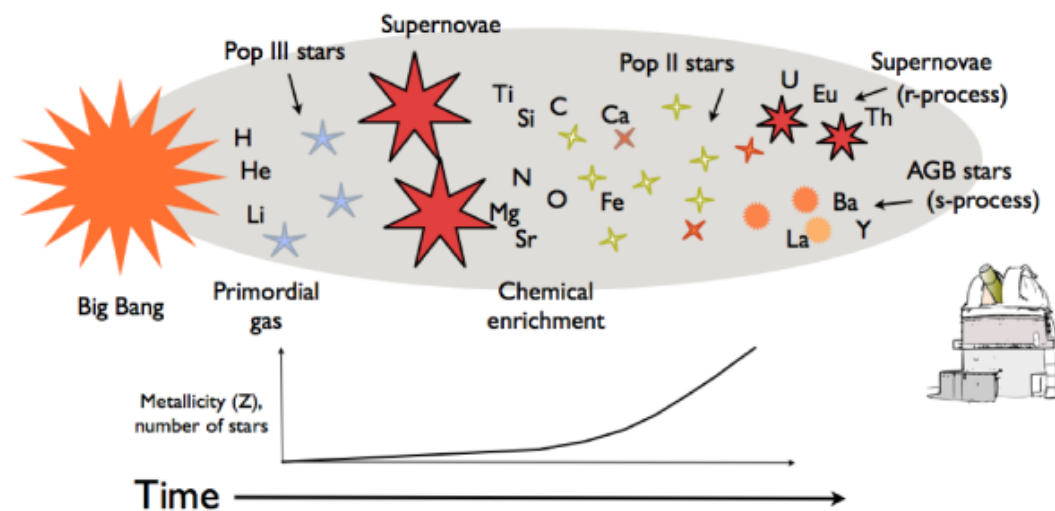
Observation of samples out to the epoch of cluster formation ($z \sim 2$)



X-IFU/Athena: entropy distribution in a $M_{500} \sim 5 \times 10^{13} M_{\odot}$ at $z=2$ cluster
(Cucchetti et al. 2018, Pointecouteau et al. 2013)

CHEMICAL ENRICHMENT

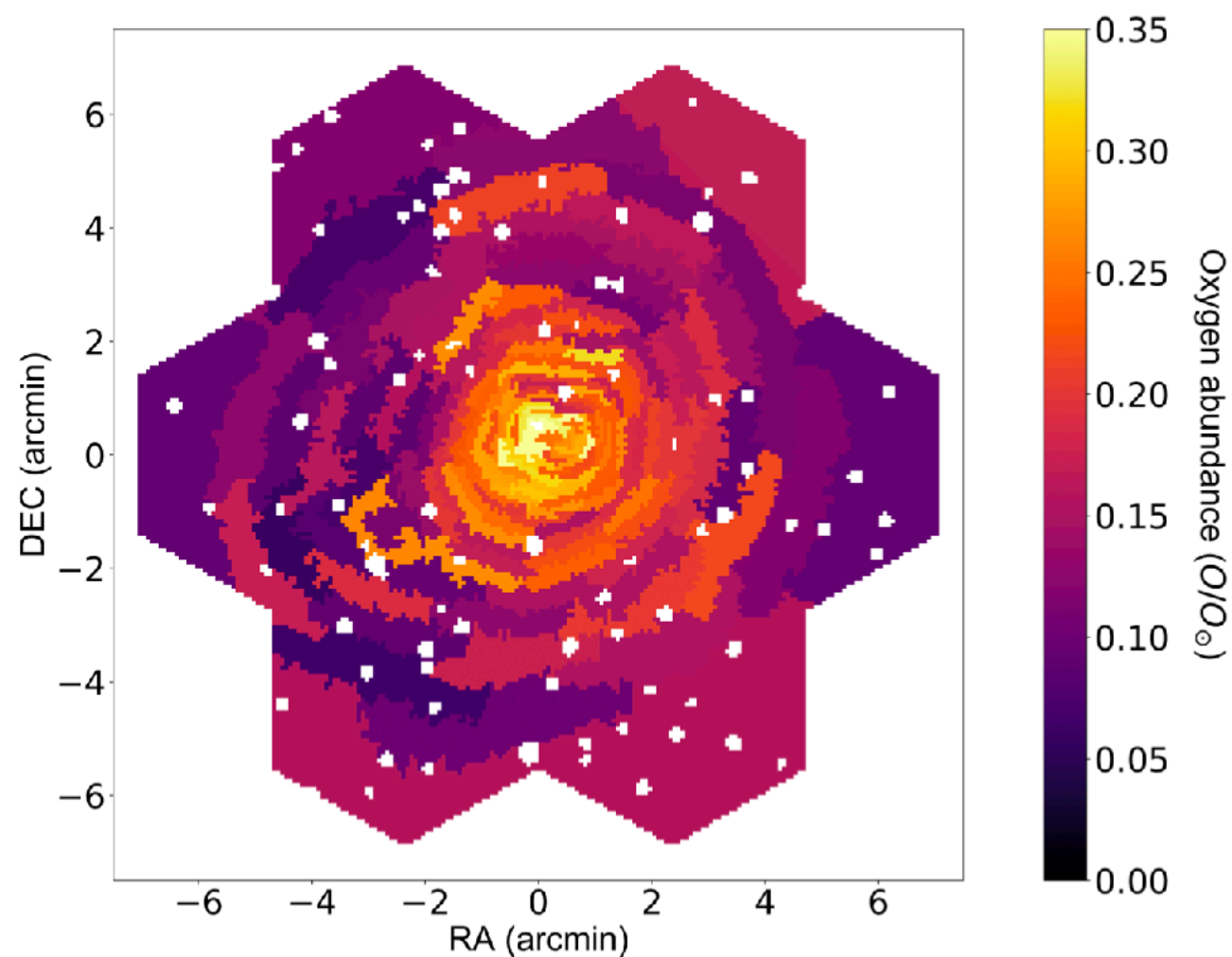
7



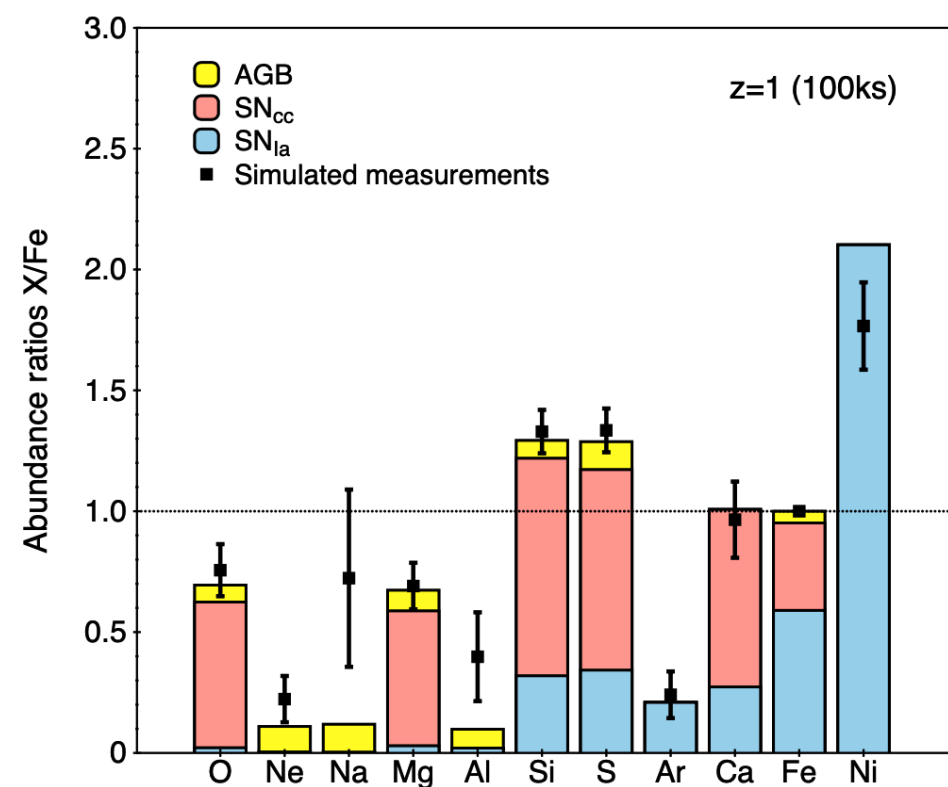
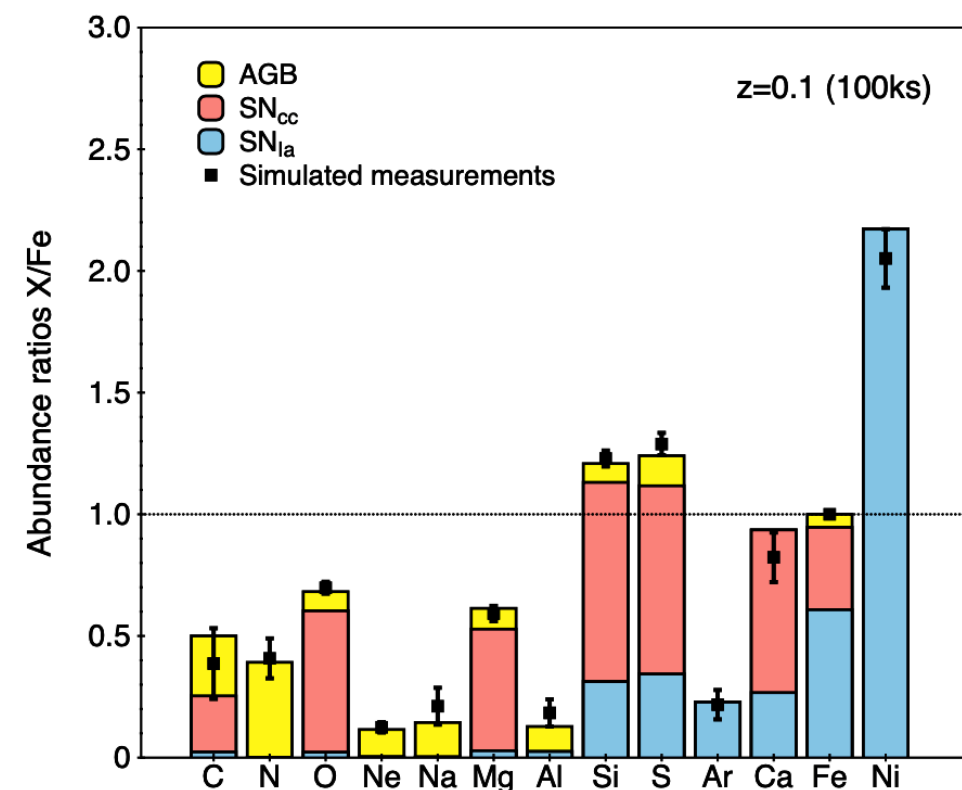
Chemical radial distribution, relative abundances, evolution
(adapted by & from Mernier et al. 2018)

CHEMICAL ENRICHMENT

8

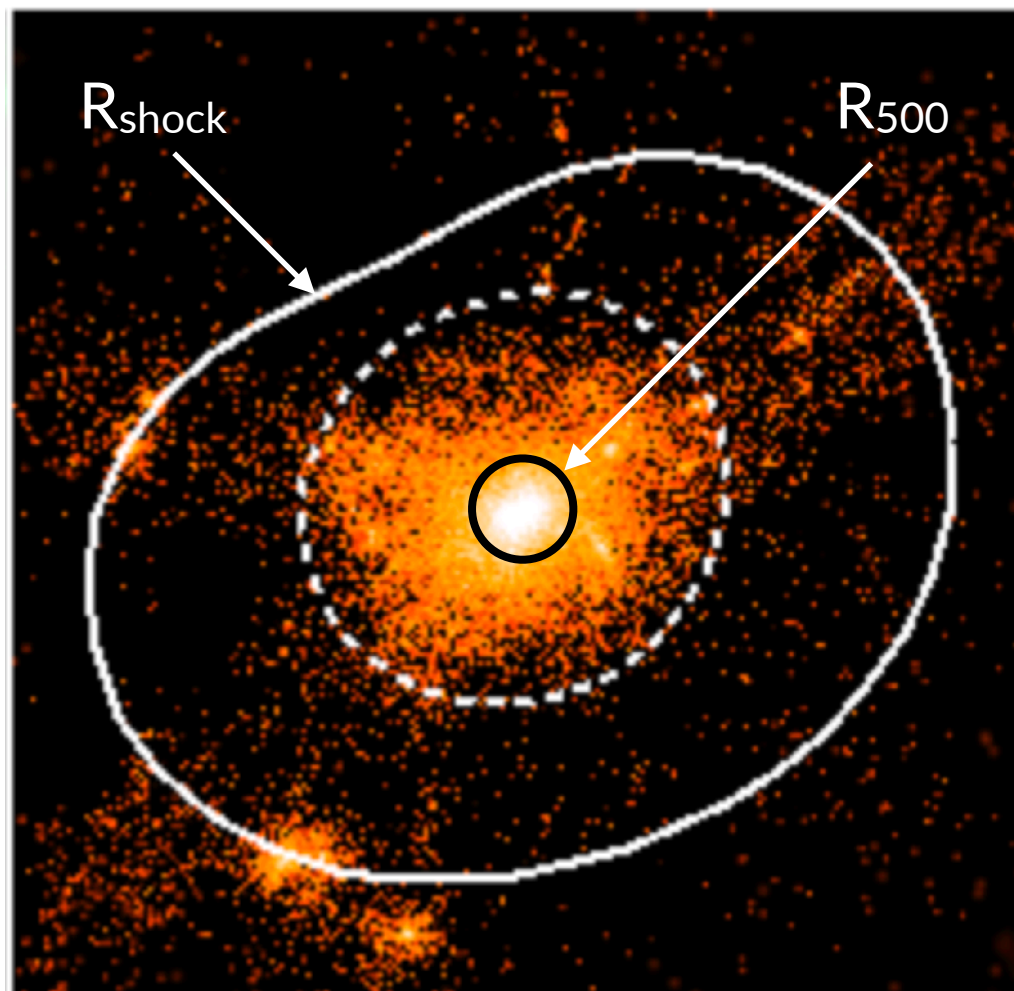


Oxygen reconstructed map and relative abundances view by X-IFU view
(Cucchetti et al. 2018, Mernier et al. 2020)

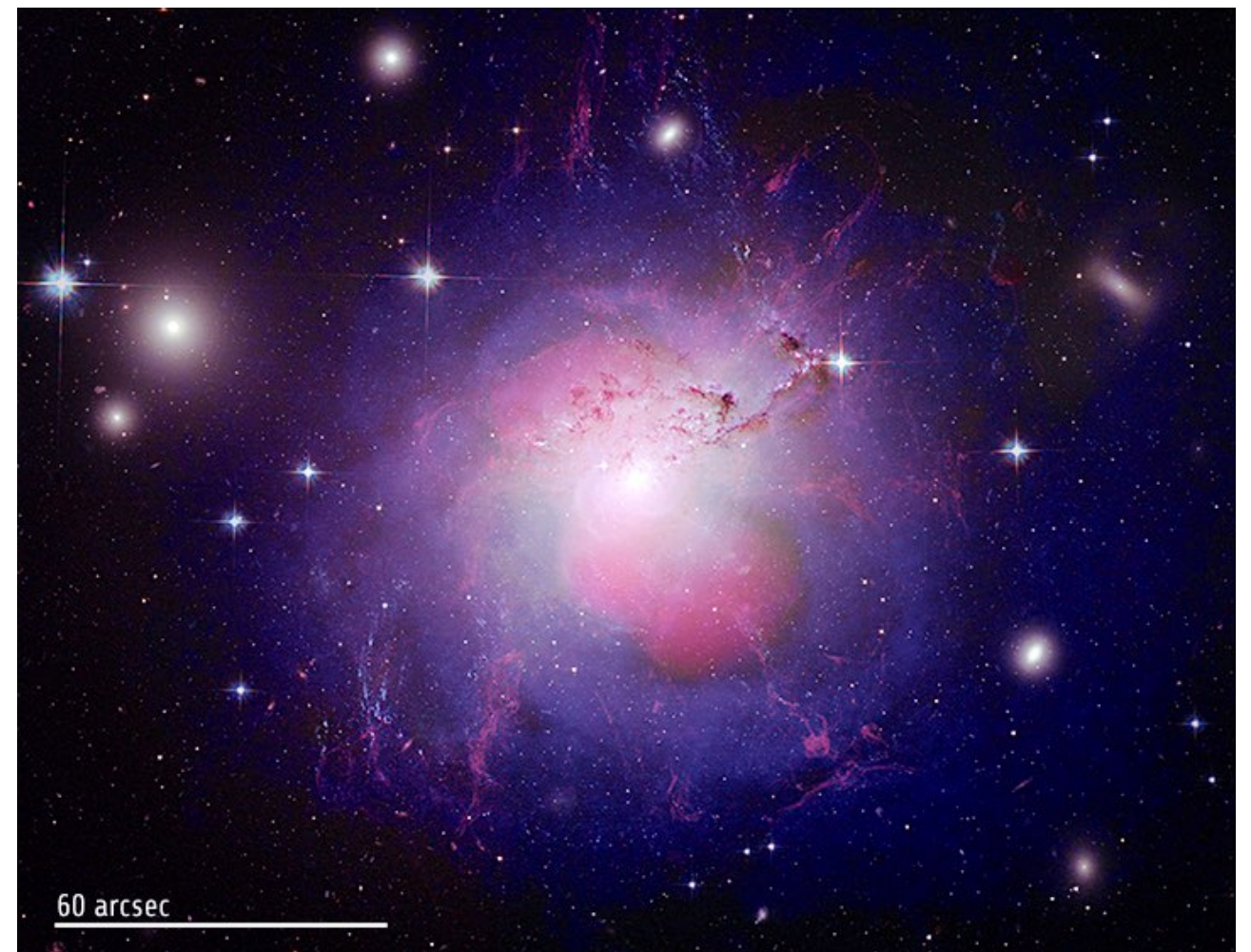


ASSEMBLY OF STRUCTURES

9



Outskirts of clusters
(Aung et al. 2020)



X-ray and panchromatic view of the Perseus
cluster core

X-ray: NASA/CXC/IoA/A. Fabian et al.; Radio: NRAO/VLA/G. Taylor;
Optical: NASA/ESA/Hubble Heritage (STScI/AURA) & Univ. of
Cambridge/IoA/A. Fabian

GAS MOTIONS AND TURBULENCE

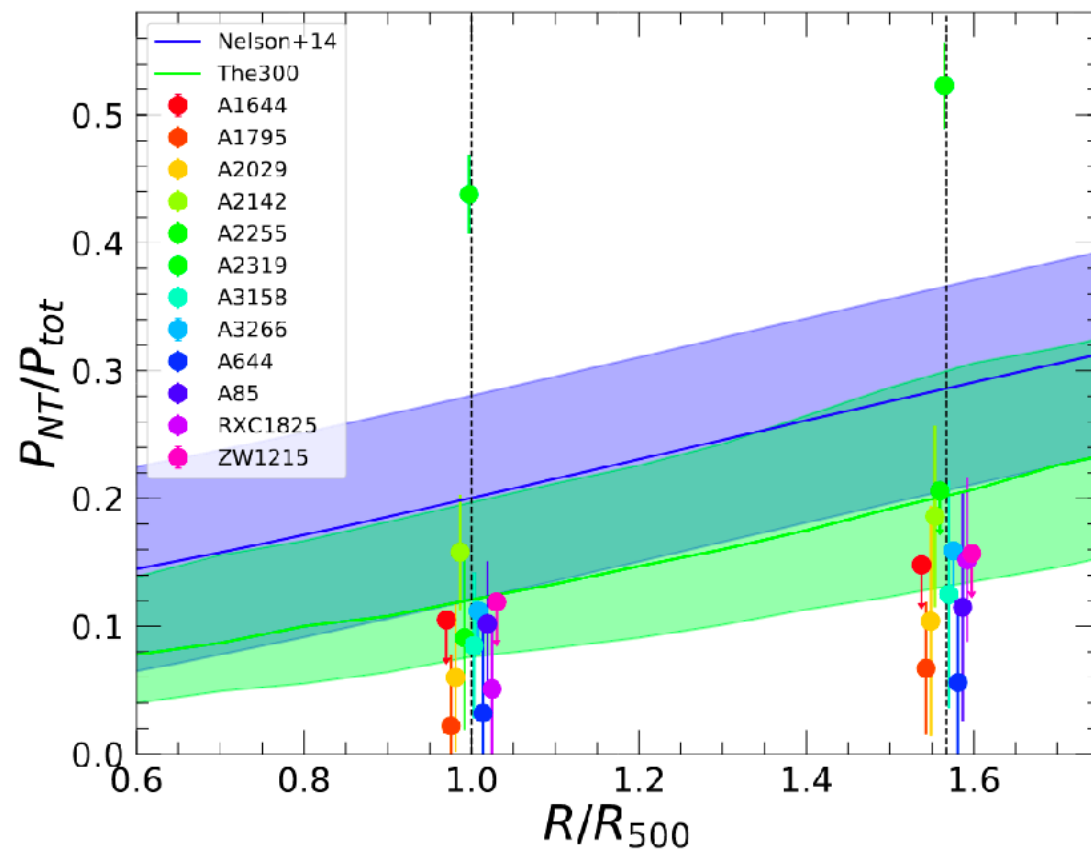
10

Measurements of turbulent and bulk motions

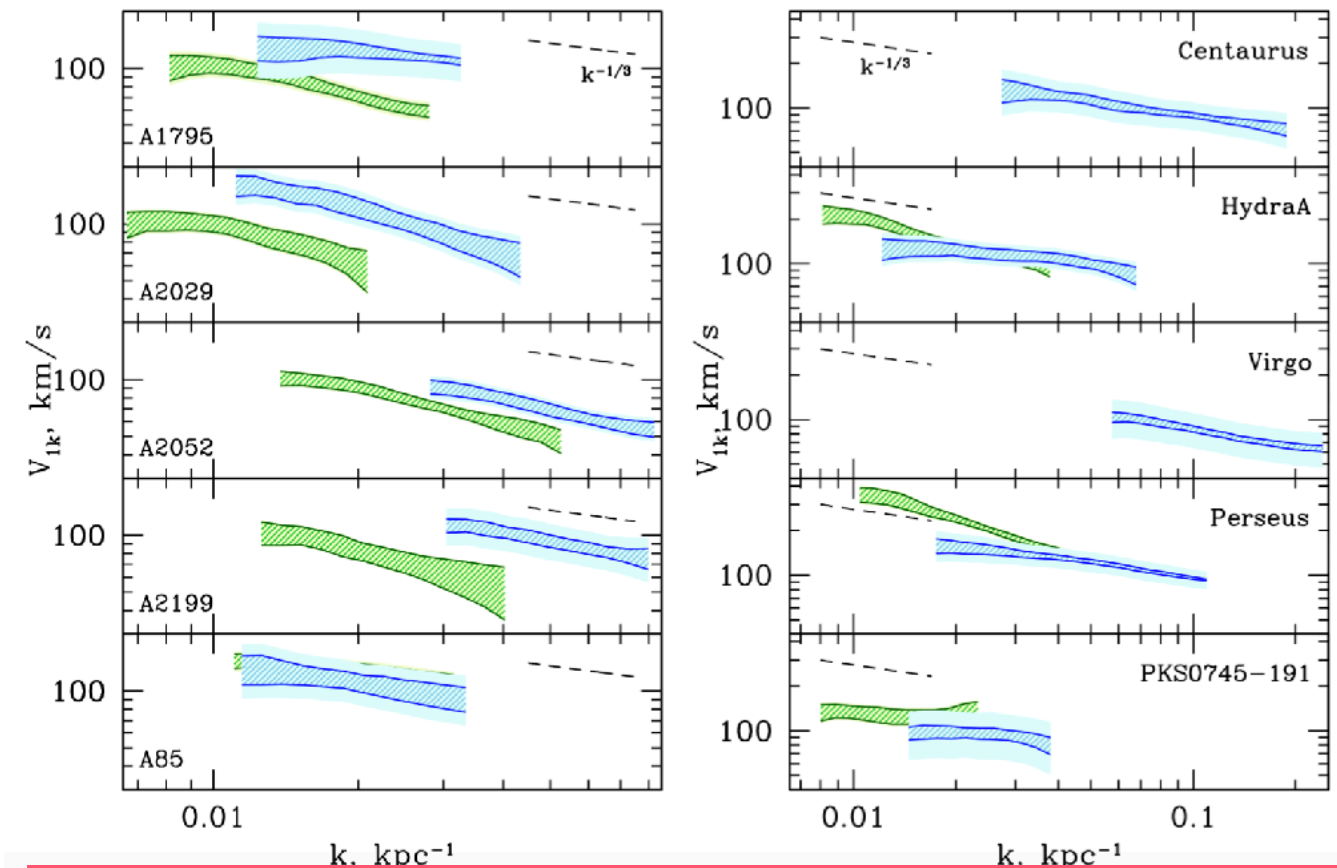
Non thermal pressure from the gas fraction

Statistics of brightness fluctuations (massive nearby clusters)

Resonant scattering (low mass systems, i.e., galaxies)



Non thermal pressure
(Eckert et al. 2019)



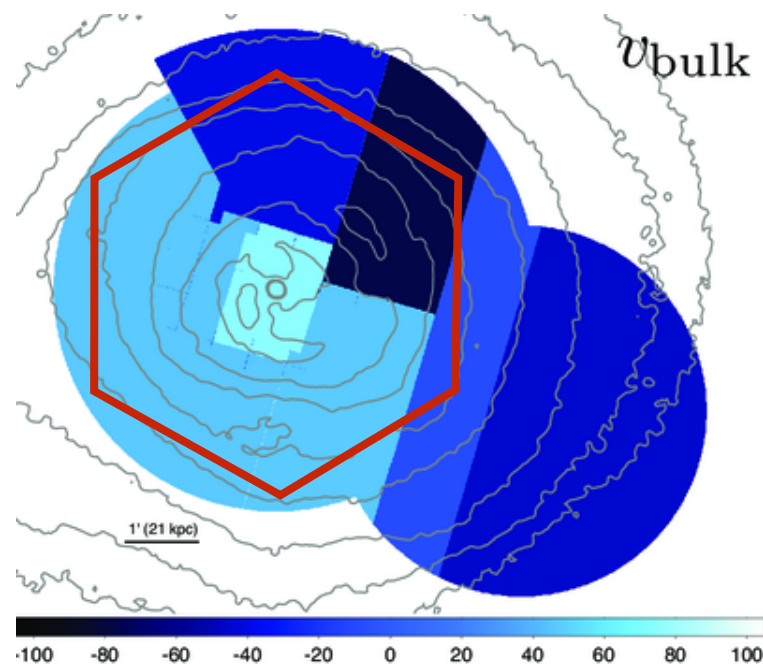
Gas velocity power spectrum
(Zhuravleva et al. 2018)

ASSEMBLY OF STRUCTURES

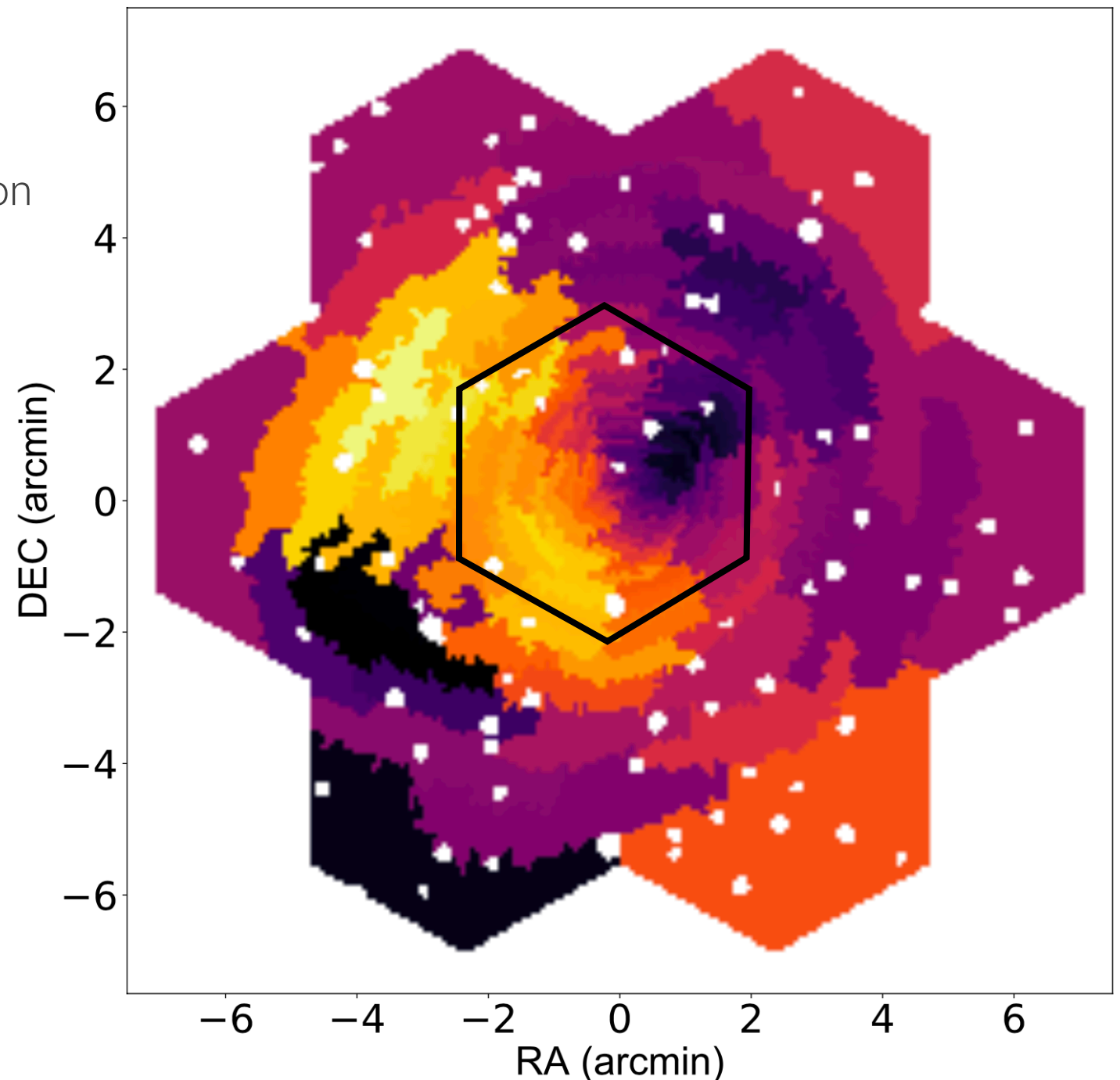
11

Direct measurements of the bulk motions and turbulent velocity fields

Shift and broadening of X-ray line emission



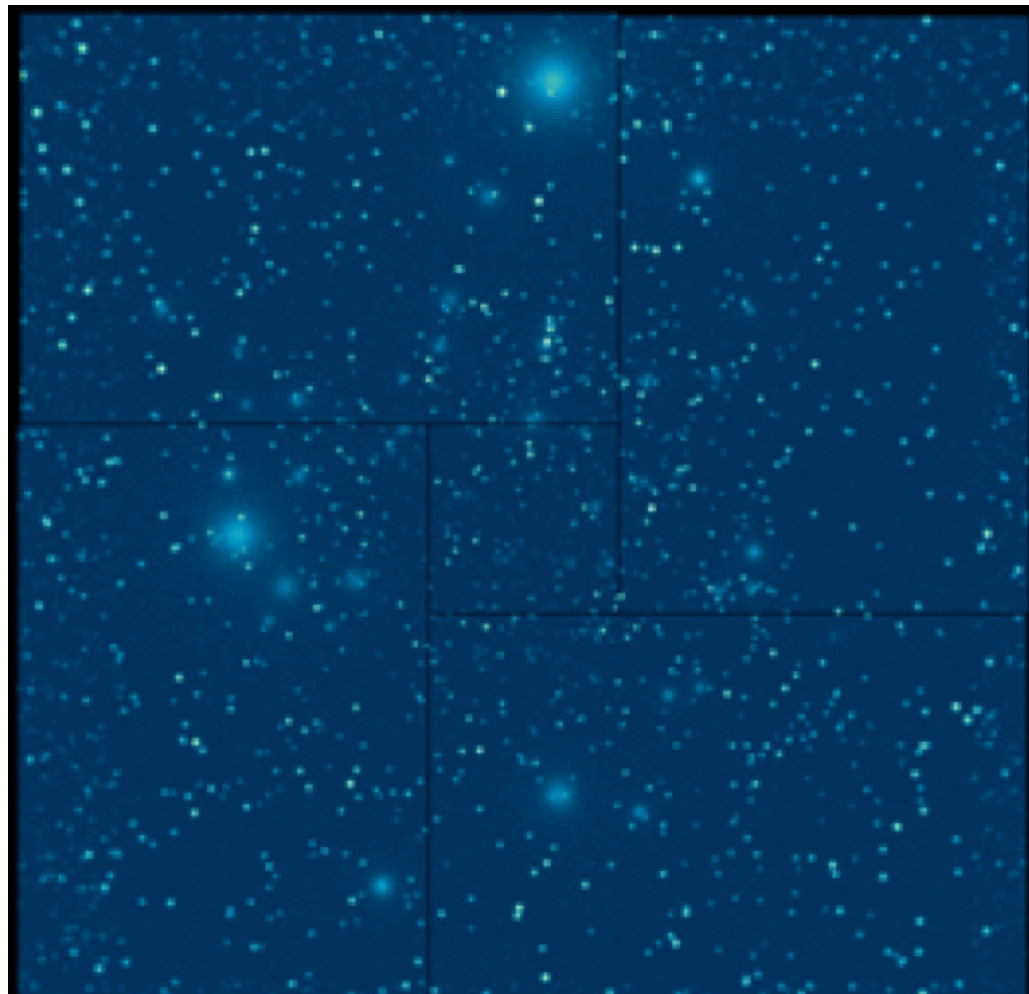
Hitomi bulk motions in the
Perseus core
(Hitomi Coll. 2017)



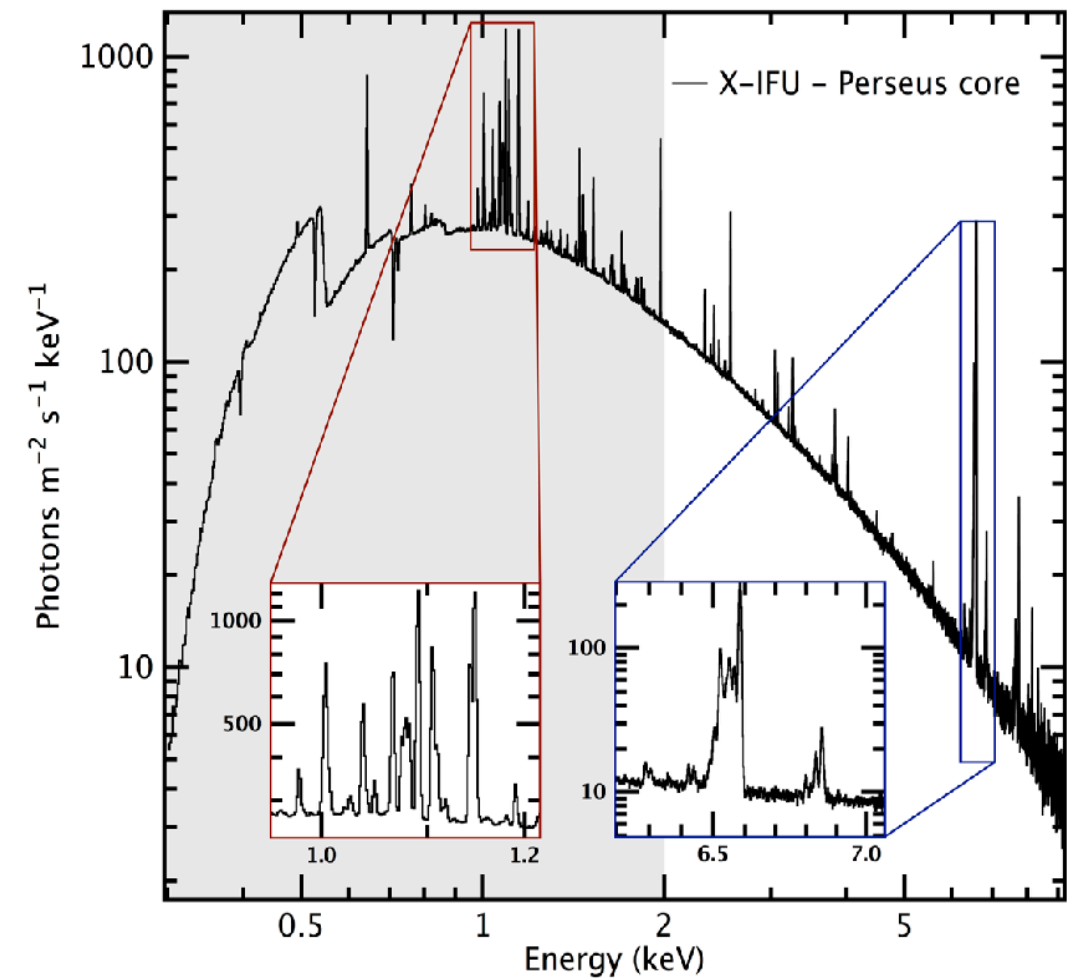
Measurement of turbulence and gas motions with
X-IFU/Athena
(Cucchetti et al. 2018,

Key characteristics

12



Wide field and survey
(Credits: WFI team)



Spatially resolved high spectral
resolution
(Credits: X-IFU team — data courtesy of C.)

The Wide Field Imager

Silicon Active Pixel Detector based on DEPFET technology

Field of view: $40' \times 40'$

2.2'' pixel size (PSF oversample)

Spectral resolution <80 (<170) eV @ 1 (7) keV

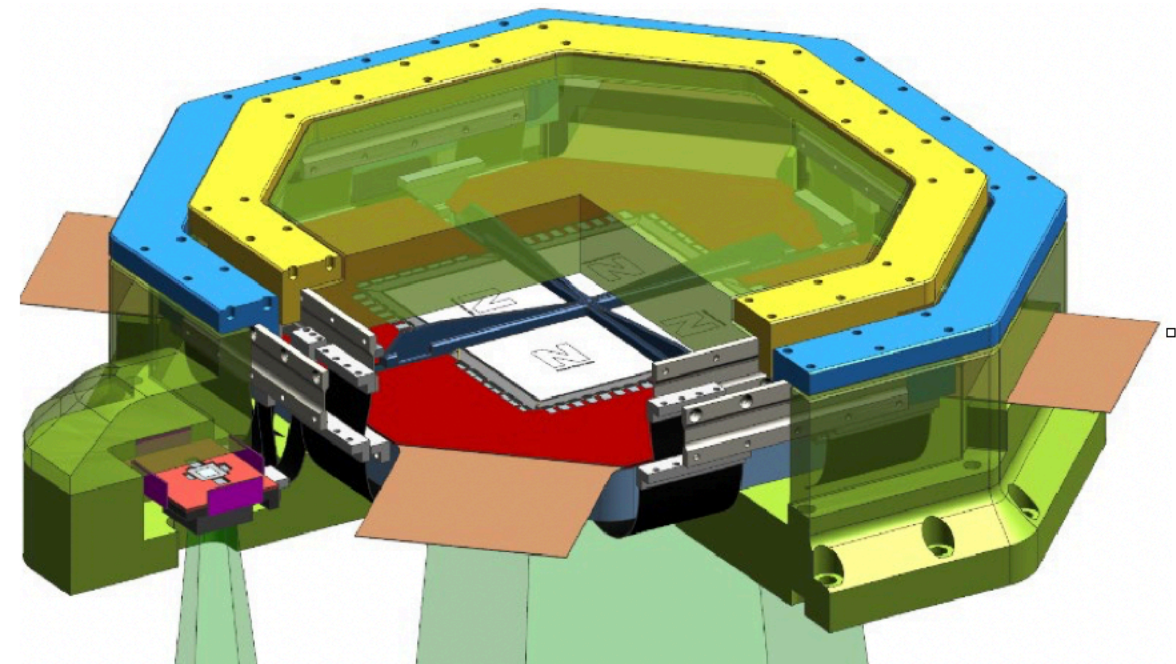
Separate chip for fast readout of brightest sources up to 10 Crab intensity

Consortium led by MPE (PI: K. Nandra)

Partners: DE, AT, DK, FR, IT, PL, UK, CH, P & GR and NASA

French contributions

CEA/DAP, ObAS



WFI focal plane assembly
(Credits: MPE & WFI team)

The X-ray Integral Field Unit

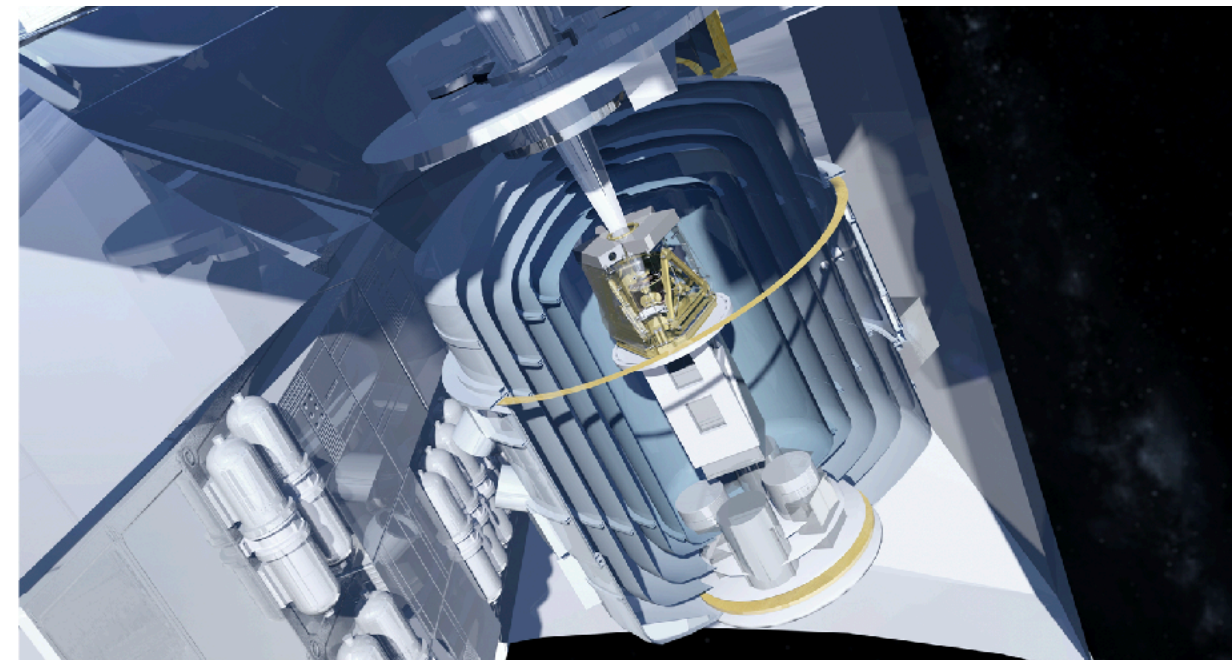
Large micro-calorimeter array (TES)
Cryogenic instrument cooled down to 50 mK
2.5 eV spectral resolution up to 7 keV
5' hexagonal field of view
Capability to observe bright sources (1 Crab, 10 eV, 5-8 keV)

Consortium led by IRAP (PI: D. Barret)

Partners: NL, IT, BE, CZ, FI, DE, IR, PL, ES, CH and contributions from Japan and US

French contributions

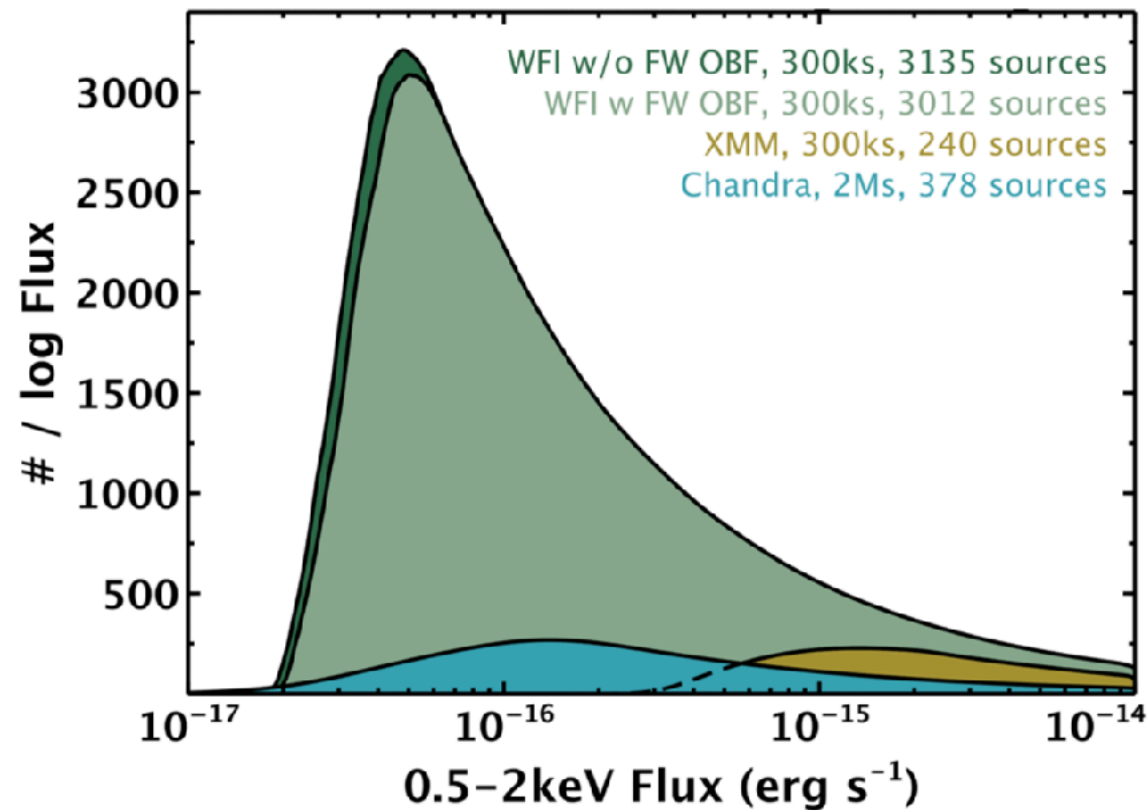
CNES is prime for the instrument
APC, CEA/SBT, CEA/DAP, IRAP, IAS, LAM, ObAS



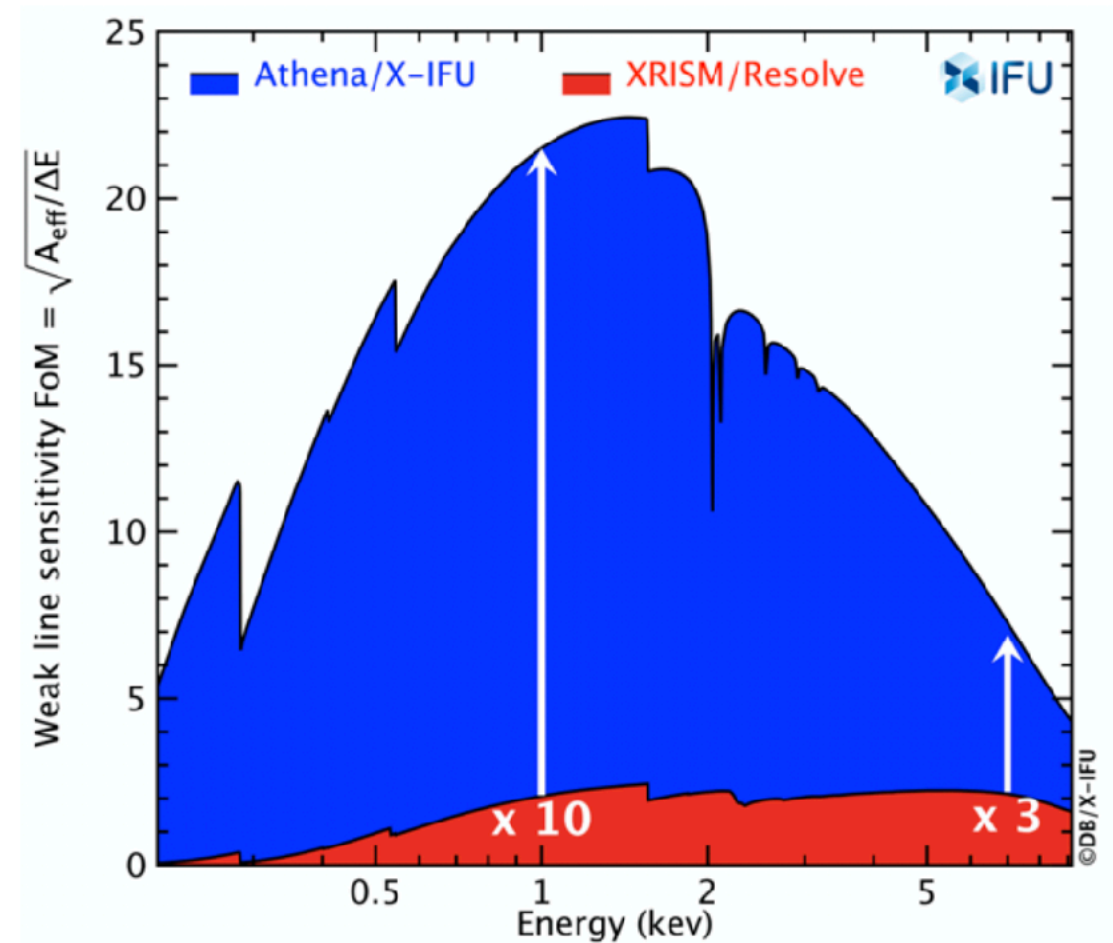
X-IFU cryostat & FPA
(Credits: X-IFU team)

PERFORMANCES

15



WFI survey speed
(Credits: WFI team)



X-IFU Weak line sensitivity
(Credits: IRAP & X-IFU team)

A leap by at least an order of magnitude in sensitivity over current or planned facilities

About 8 times more sources pointing in ~7 times shorter exposures with WFI (compared to Chandra)

10 times weaker lines detected with X-IFU (compared to XRISM)

ATHENA

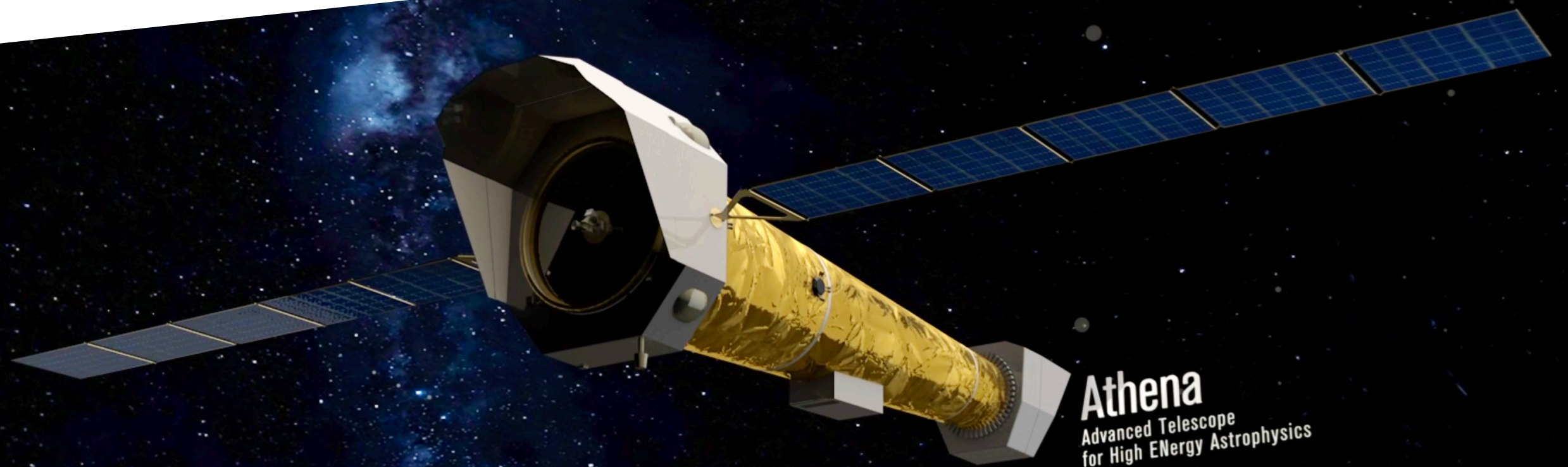
16

Milestones

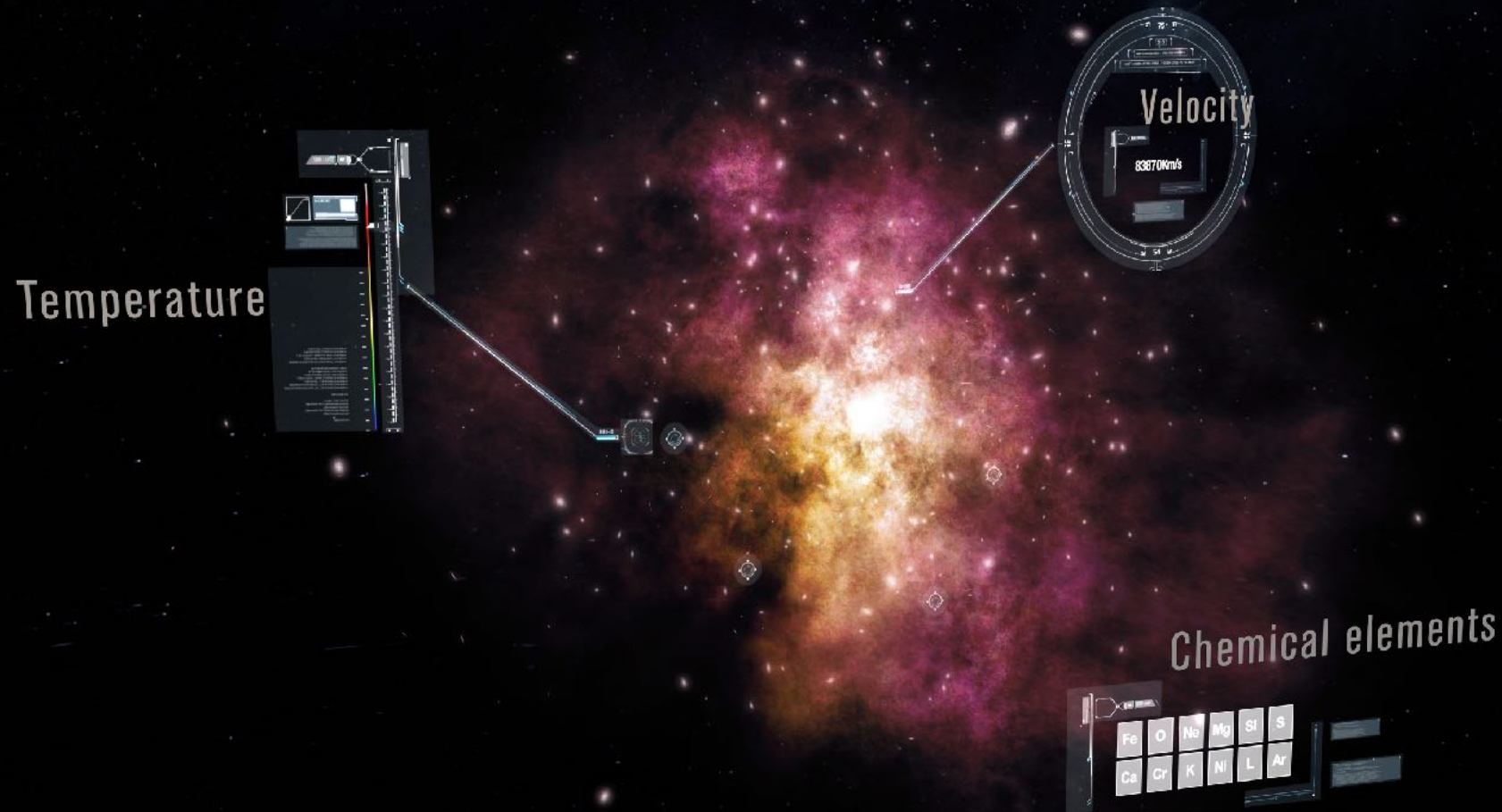
Redbook prepared together with A&A support papers by the community for June 2021
Adoption of the mission by ESA in 2022
Flight model delivery to ESA in 2029
Launch on board an Ariane 6 in the early 30's

Athena is rising on the horizon

Technology is ramping up and instruments are being developed
Your next generation X-ray observatory
Stay tune and get involved!



CONCLUSIONS



A Versatile Observatory

Serving many astrophysics domains and a broad community



Transformational capabilities

Spatially resolved high resolution spectroscopy
Wide field imaging



A strong French involvement

X-IFU is a cryogenic instrument, using cutting edge technologies.